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EVALUATION OF THE TRANSIENT ELECTROMAGNETIC METHOD AS APPLIED IN WADI-FILL DEPOSITS, SOUTH SINAI, EGYPT

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تقييم لطريقة الحث الكهرومغناطيسى كتطبيق فى رسوبيات الأوديه جنوب سيناء – مصر

الخلاصة: يعتبر وادى فيران من المصادر الرئيسيه للمياه الجوفيه فى جنوب سيناء . نظرا" لتعقد التركيب الطبقى لمثل هذه الأوديه وعدم تجانس المكونات الصخريه وكذلك لوجود تتابعات من الطبقات الكهربيه العاليه والمنخفضة المقاومه، فإن هذا الوضع الطبقى يعطى صوره غير واضحه للتراكيب التحت سطحيه والمياه الجوفيه عند أستخدام طرق المقاومه الكهربيه التقليديه. ولذلك تم أستخدام طريقة الحث الكهرومغناطيسى فى المدى الزمنى كطريقه حديثه لا تتأثر بعدم التجانس القريب من السطح . تم قياس عدد ٢٣ محطه كهرومغناطيسيه وعدد ٢ جسه كهربيه متعامده بترتيب أشلمبرجيروذلك حول ٧ آبار مياه جوفيه متواجده فى المنطقه . أعطت النتائج صوره واضحه للتتابع الطبقى وخزان المياه الجوفى بالمنطقه وكانت بمثابة تقييم جيد لأستخدام طريقة الحث الكهرومغناطيسي فى المدى الزمنى مع الأخذ فى الأعتبار أن عمل نموذج ثلاثى الأبعاد يعطى تفاصيل أدق فى مثل هذه البيئات الوديانيه.

ABSTRACT : *Wadi Feiran is considered one of the main sources for groundwater in Southern Sinai, Egypt. The stratigraphic make-up of such wadi is complex with the presence of near surface inhomogeneties and alternations of resistive and conductive layers. This could produce undesirable results in subsurface imaging using DC resistivity method. Therefore, TEM as an alternative tool which is less affected by distortion from near surface anisotropy has been evaluated and assessed for lithological identification, aquifer characterization and direct removal of static shift in DC sounding curves in such wadi. Twenty three single loop TEM and two Schlumberger VES soundings have been carried out around seven boreholes in the area of study. The output results have shown the effectiveness of the proposed TEM method in handling of such wadies. However, it is recommended to use a contiguous transient electromagnetic profiling and 3D modeling for obtaining highly resolved mapping in such environments.*

INTRODUCTION

Transient electromagnetic (TEM) method is an inductive method that utilizes strong current which is passed through a rectangular loop commonly laid on the surface of the ground. The flow of this current in the surface loop creates a magnetic field that spreads out into the ground in the form of a primary magnetic field and induces eddy currents in the subsurface.

Recently, transient electromagnetic (TEM) method is widely used for hydrogeological, engineering, and environmental applications (e.g. Kafri and Goldman, 2005, Rubin and Hubbard, 2005). This is attributed to its ability for penetrating thick conductive overburden overlying resistive bedrock targets (Meju et al., 1999). TEM method has shown its efficiency as an integrated method with Vertical Electrical Sounding (VES) and Audio-Magnetotelluric (AMT) methods in the semiarid areas (c.f. Mohamed et al., 2002). On the other hand, TEM has been used to correct the DC and MT data for the so called static shift since it is less affected by near surface inhomogeneities .

In this study, transient electromagnetic method has been carried out in typical wadi fill deposits of Wadi Feiran, which is considered one of the main sources for groundwater in southern Sinai, Egypt (Fig.1). Sedimentations in such Wadi are complex and consist of poorly sorted flash-flood deposits and normal alluvial deposits originated from local lacustrine or swampy conditions (Issar and Eckstein 196). However, in spite of the possible presence of a complex stratigraphic sequence and near-surface inhomogeneities, discrete direct current resistivity soundings are commonly made in such Wadis (e.g. El-Gamili et al., 1994; Shendi, 2001) at widely spaced stations and which could produce undesirable results in subsurface imaging. Therefore the TEM method has been evaluated in this study as a cost effective rather than the DC resistivity method, which sometimes gives unreliable results and when even applied needs massive effort to carry out in this complex lithology of thick resistive overburden overling alterations of conductive and resistive layers (Fig.2). Twenty three single loop TEM and two Schlumberger VES soundings were conducted for lithological identification, aquifer characterization and direct removal of static shift in DC sounding curves at the outlet of Wadi Feiran.

Acquisition and Processing of TEM and DC resisivity data

The TEM data have been collected in Oct. 2005 by Sirotem equipment, an Australian built field system. It consists of a transmitter and a receiver components housed together and powered by two 12 volt batteries.

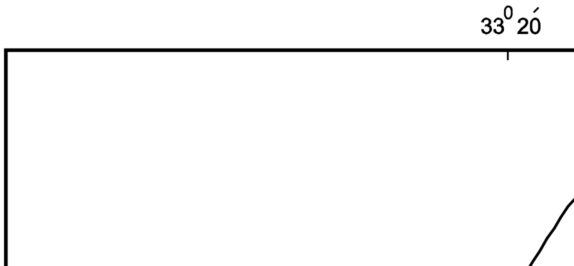


Fig.1: Location map of the area of study showing the locations of TEM-VES and boreholes

Single-loop TEM data were acquired at these sites using 50 m-sided transmitter loops and the spacing interval was 150m. The time window bands applied were composite, high resolution and early time series. Composite time series was mainly selected in processing to get at large extent a greater depth of investigation. The recording number of windows selected varied depending on the quality of data. IP effect has been reported as negative response over some range of the measurement at late time which has not been accounted for. In the mean time, two vertical electrical soundings have been done at two sites (Fig.1) using Shclumberger array with maximum AB/2 equal to 500m. The equipment used is Syscal/R2 resistivity meter.

The TEM voltage measured has been converted into its late stage apparent resistivities (Kaufman, 1983).

The late time apparent resistivities calculated were plotted versus time. A simple approximate scheme for TEM data sets (Meju et al. 1999) have been evaluated and assessed to see whether it can be applied in these heterogeneous conditions for obtaining an initial model especially if there is no previous information. Therefore, TEM apparent resistivity data have been converted before modeling into effective subsurface resistivity at depth yielding a continuous picture of the resistivity-depth distribution of the subsurface (Fig. 3). 1-D modeling was then used for forward and automatic inversion approaches of the TEM data set (Meju, 1994). This program takes the turnoff time effect into account. The inverse modeling was done on the preliminary model and ridge regression method was used to adjust iteratively the parameters of the starting model until obtaining a model that best fits the data.

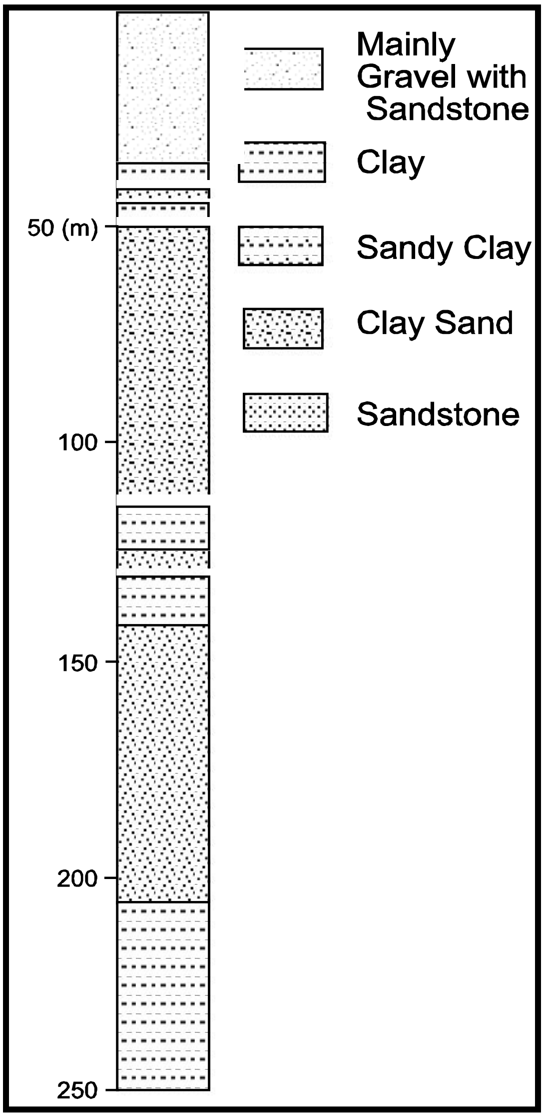


Fig. 2: Lithostratigraphic column borehole site Wf16.

1-D Synthetic response

VES and transient electromagnetic (TEM) 1D response were calculated for the known subsurface resistivity distributions at site WF11 and WF13, which have complex lithology and alternations of conductive and resistive layers. The TEM data for various transient times are plotted at their equivalent AB/2 spacing using an approximate scaling relation (Meju et al., 1999). Synthetic response shows that The TEM responses generally proved to be better for defining the conductive units (Fig. 4). The contrast between the geoelectric layers is clearly shown in the TEM synthetic data. These TEM depth soundings can be efficiently conducted in geometrically restricted areas of Wadi Feiran where it is difficult to expand the current electrodes of DC rsistivity method beyond 500 m to reach the potential aquifer which is at depths greater than 170 m in such wadi.

Static shift correction

Electric and electromagnetic methods are still affected differently by the presence of small-sized three-dimensional (3D) bodies in the near-surface. It is still an unresolved problem in geoelectrical exploration (e.g. Barker 1981; Groom and Bailey 1989). Essentially, TEM method is less affected by near surface inhomgeneity than the DC resistivity method which might be vertically shifted on sounding curves (Meju et al, 1999). Therefore, the main tenet of collecting DC resistivity data is to see whether TEM method can be applied in heterogeneous geological media, enabling accurate identification and removal of static shift in DC resistivity sounding curves. Subsequently electrical and EM depth-sounding techniques can be combined to yield more complete profiling of the resistivity of the subsurface. Joint DC and TEM soundings were executed at two sites then simple approximate schemes (Meju et al, 1999) for DC and TEM data sets, have been applied in these heterogeneous conditions.

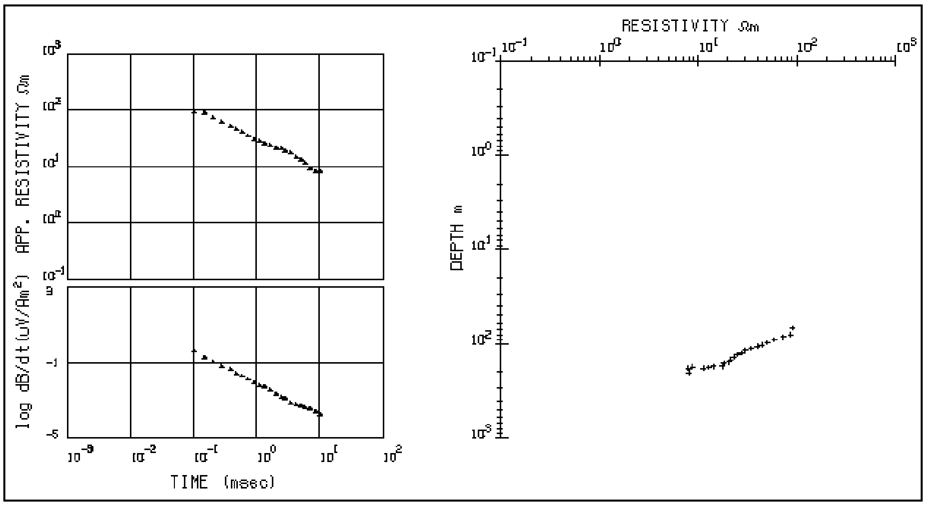


Fig 3: An example of TEM resistivity-depth transformation at sit W23.

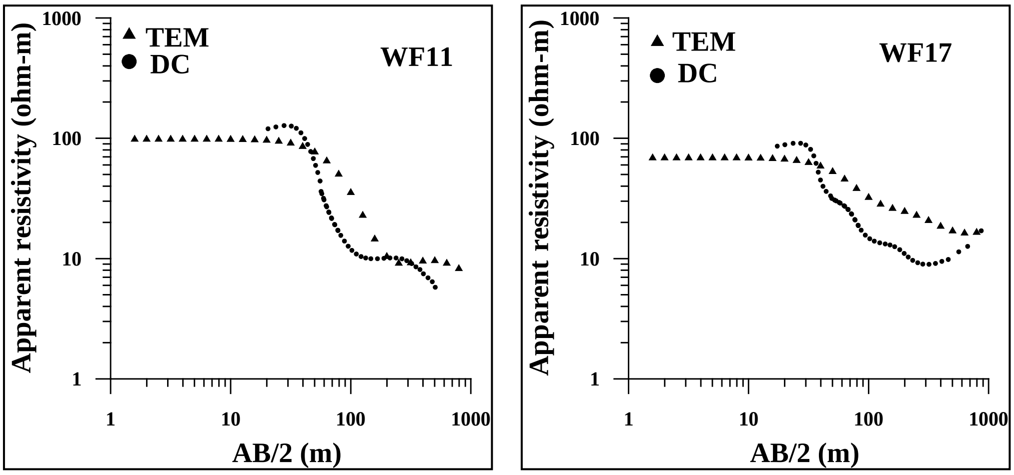


Fig. 4: Synthetic response of broadband TEM and VES 1D apparent resistivities calculated for two borehole sites (WF11 and WF17) using the average values of the resistivities recorded in the boreholes.

Selective example is given in (Fig. 5a). Note the good correlation between resistivity data and TEM data after the removal of static shift effect (Fig. 5b) and the ranges of resistivity values get closer to those recorded by resistivity log (not shown here) at the same location.

TEM modeling and the effect of a priori information

The resistivity-depth transformation and 1-D forward and inverse modeling results have been conducted to the collected TEM data. The initial model was designed from resistivity logs of the boreholes after doing environmental corrections. Figure (6) shows the forward modeling at site w8. The initial model was selected at the nearest borehole (WF14) beside the site taking any guidance from TEM resistivity-depth transformation. As shown, the fit between observed and calculated data is generally good. Note the agreement between the resistivities of layer boundaries with the changes of resistivity-depth transformation.

However, inverse modeling was carried out to get the best fit and through it the thickness of the third resistive layer has become thinner than realism. Generally, most of TEM data set collected at the borehole illustrate that the forward response from the initial model was plausible with the observed data. Selective examples of 1-D inverse modeling results are given at sites W7, W9, W13, and W2 beside boreholes WF13, WF12, WF11, and WF16, respectively (Figs. 7, 8, 9, 10). These figures demonstrate that the initial models have been deduced from the recorded resistivity logs taking into consideration depth to water. In these models, the thick resistive and conductive zones are clearly defined and their boundaries are concordant with the alterations of resistivity-depth transformation which could be very useful for getting a starting model if there is no previous information. The distinction between the clay layer and the water bearing formation could be delineated. This is attributed to the high sensitivity of the TEM method for detecting conductive zones.

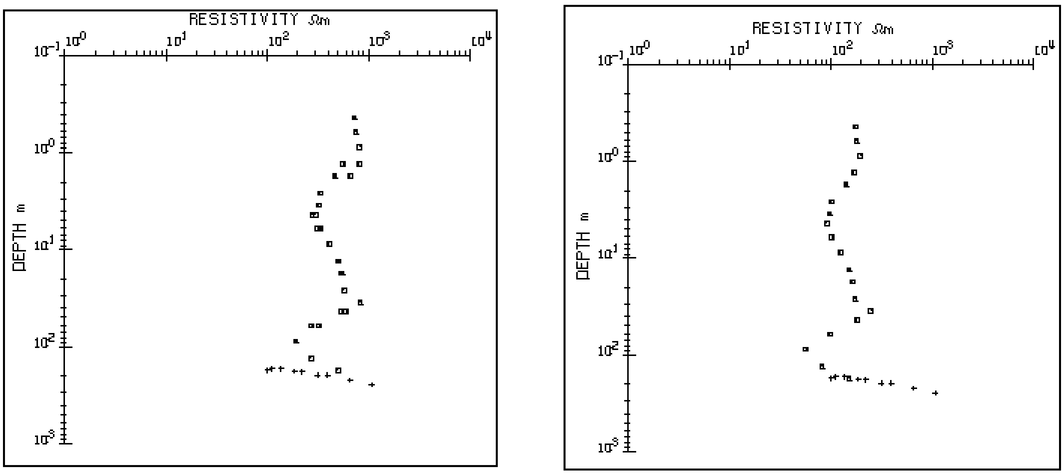


Fig.5: DC resistivity data before and after the removal of static shift at sit wf16.

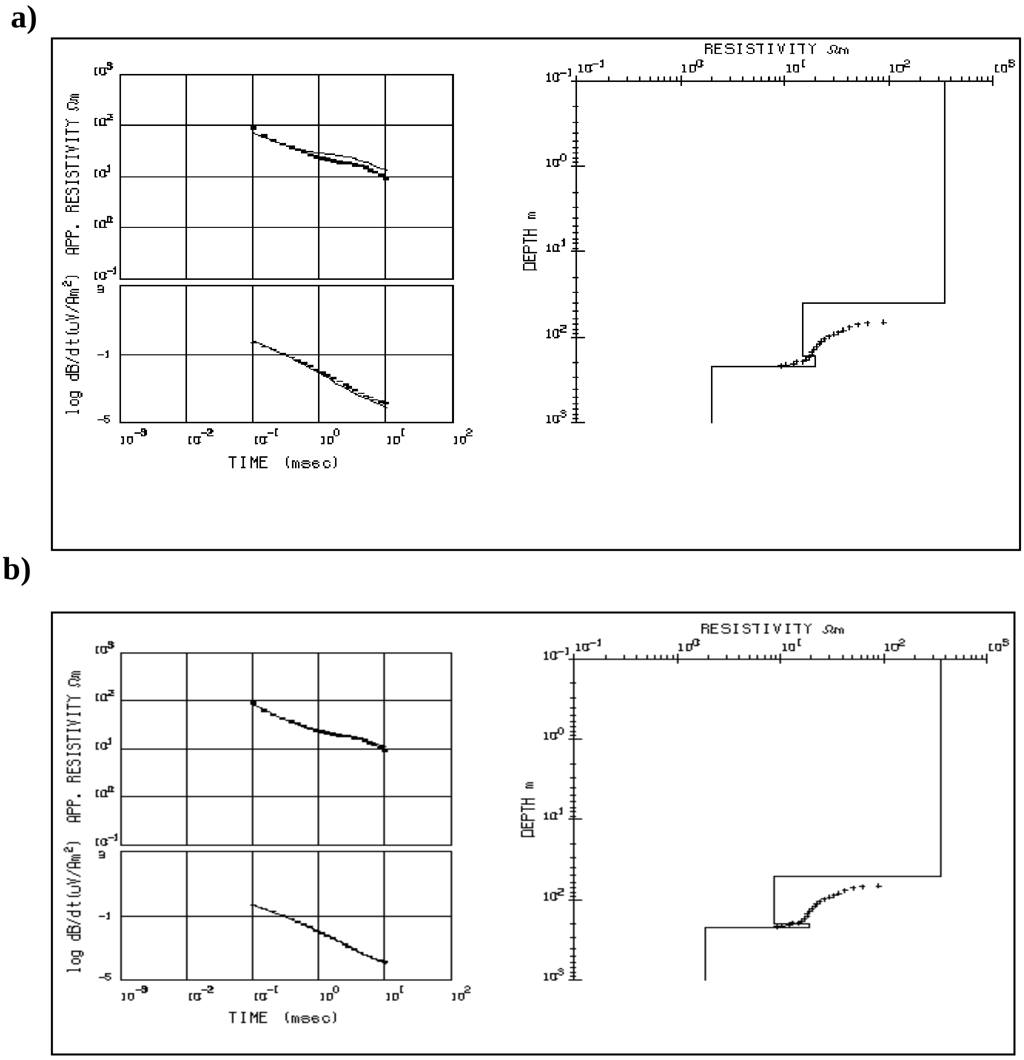


Fig.6:1-D forward and inverse modeling results of TEM data at site W8.

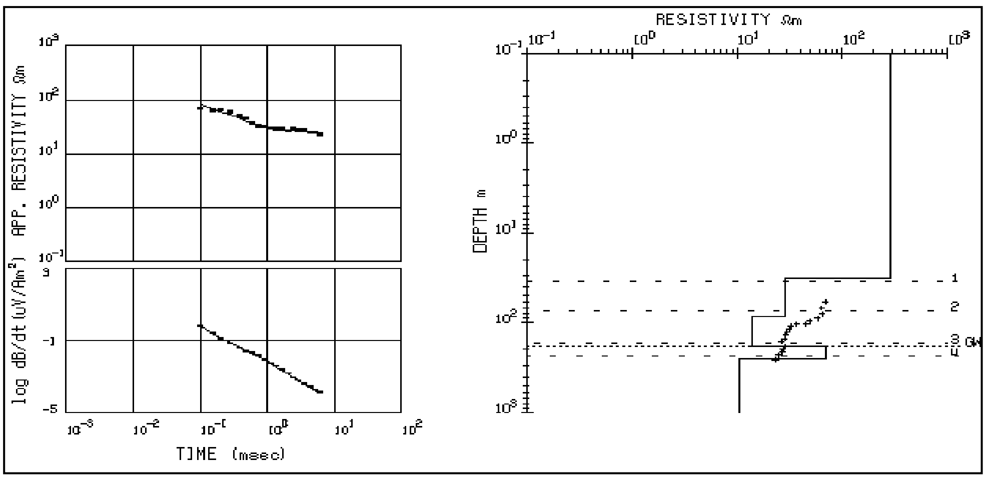


Fig. 7: 1-D inverse modeling of TEM data at site W7 beside the borehole WF13 (the lihological boundaries and depth to water are indicated.

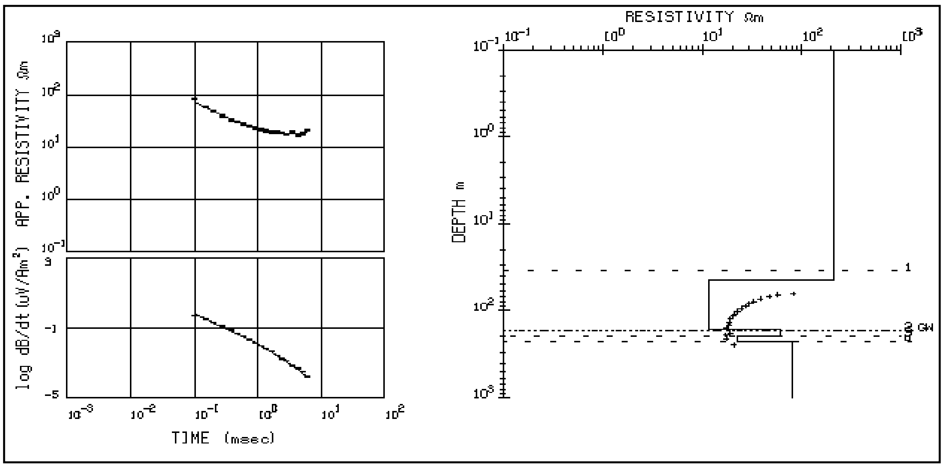


Fig.8: 1-D inverse modeling of TEM data at site W9 beside the borehole WF12.

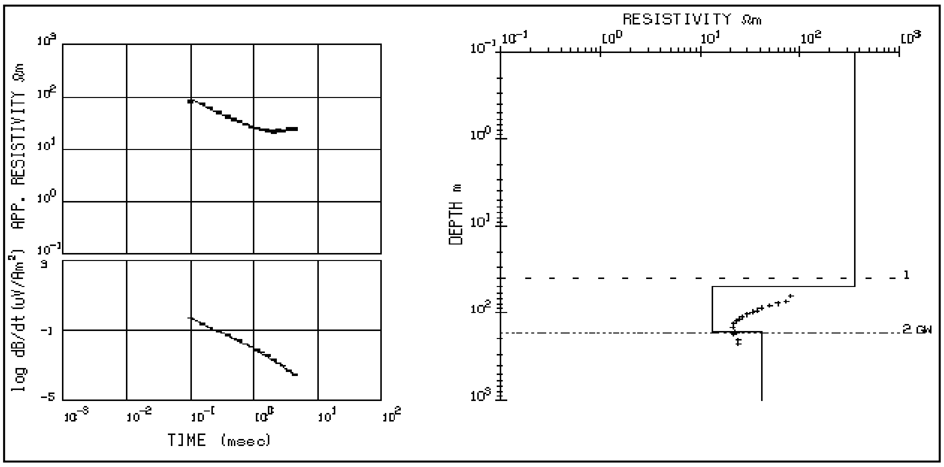


Fig. 9: 1-D inverse modeling of TEM data at site W13 beside the borehole WF11.

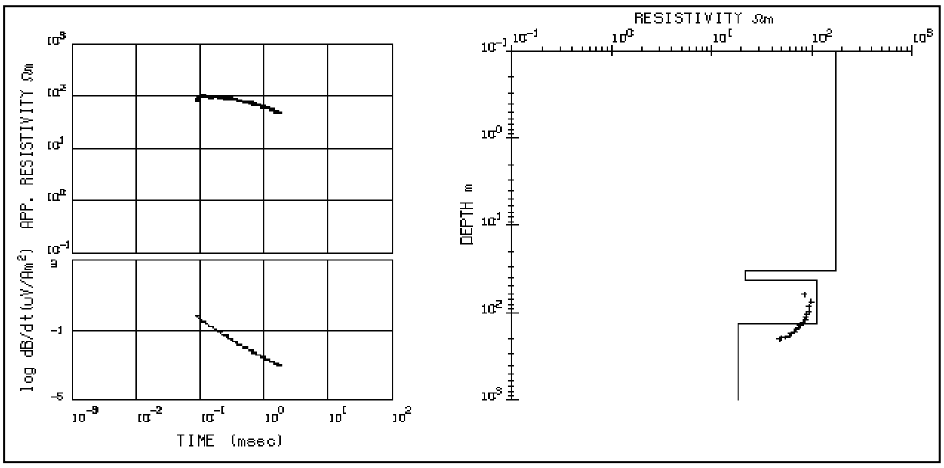
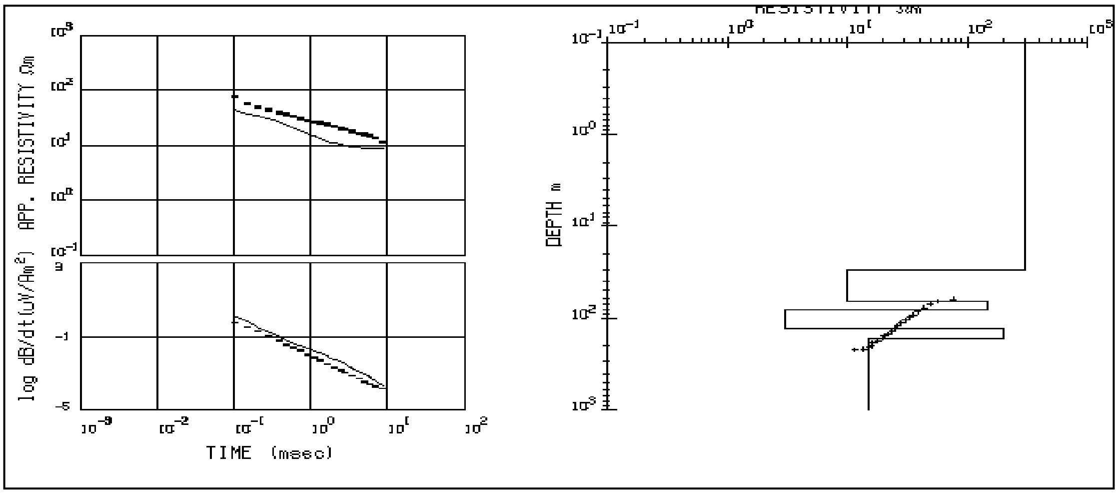
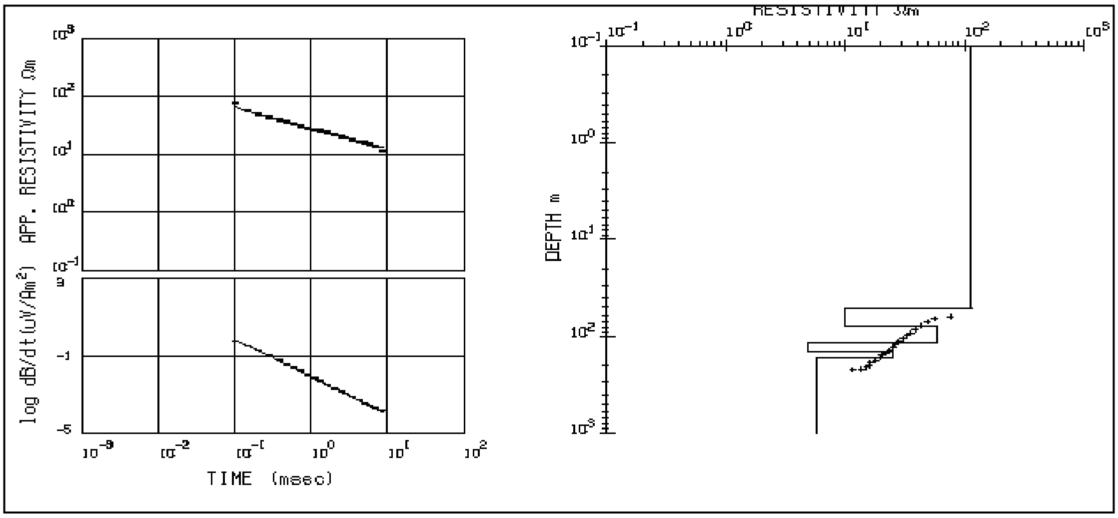


Fig. 10: 1-D inverse modeling of TEM data at site W2 150m away from borehole wF16.

a)



b)



c)

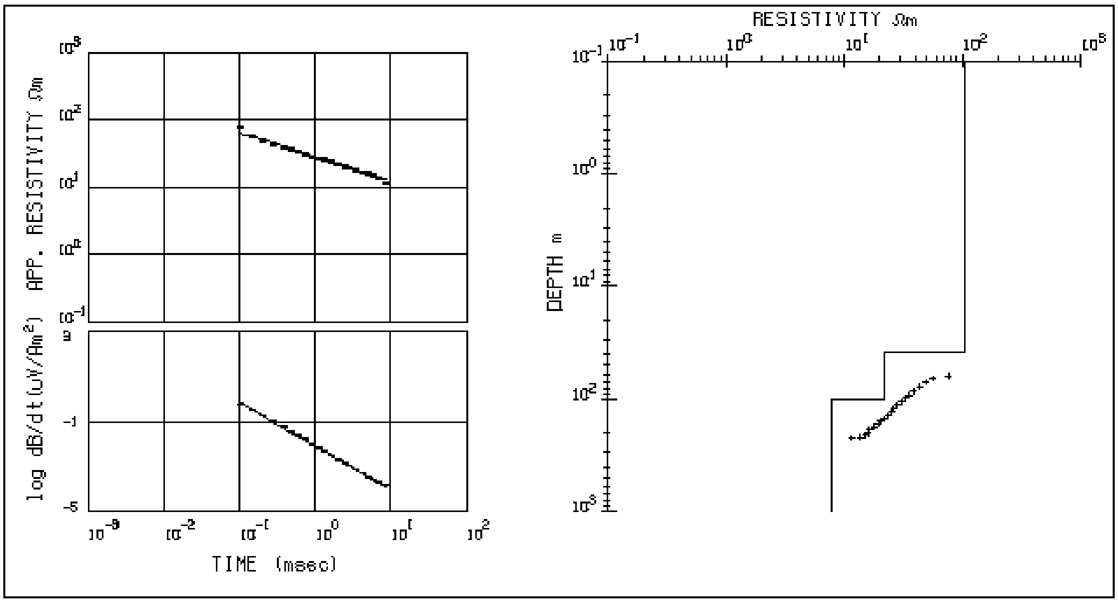


Fig. 11: Forward and inverse modeling results at site w11 beside the borehole site wf17.

Although, TEM has shown its consistency with geological and hydrgeological background, the forward response derived from a priori information represented at site w11 was not reasonable with the observed data (Fig. 11a). The inferred initial model deduced from well logging records at this site displays alterations of resistive and conductive layers. As illustrated, the fitness is actually not sensible enough in this filed example. The inverse modeling results has enhanced the fitness, though the thickness-resistivity values of layers had changed (Fig 11b). If we are not guided by geological information, and according to the effect of non-uniqueness, very simple model could produce the same fit and the resistivity-depth transformation might lead defining the preliminary model (Fig 11c). Nevertheless, the data at this site penetrated the top resistive layer and delineated the underlined conductive layers.

One dimensional geoelectric cross-section

The output results of 1-D inverse modeling of TEM data were collated to produce geoelectric cross sections. We have presented some of them along two profiles. The first one (A-A') passes through some of the available boreholes and TEM data beside them were only selected for comparative study with the geological information (Fig12) The other profile includes all the TEM data collected along that profil. In profile A-A', a priori information was used from geological information as input for inverse modeling results.

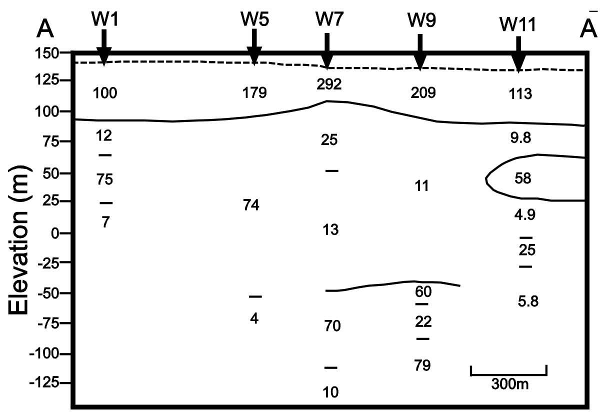


Fig.12: 2-D geoelectric section along profile A-A- using 1-D inversion results

Comparing the output results of TEM data along profile A-A' with the geological cross section along the same profile (Fig. 13), shows a good agreement, where the overlying resistive layer of gravel is well delineated. The underlying thick conductive layers of clay are also defined. However, the thin layers of clay and sandstone cannot be clearly demarked at some sites (e.g. w5) to merge together in one geoelectric layer. The margin between the resistive layer of gravel and the underlying conductive layer is reasonable with an error that does not exceed ~3m at some boundaries. The second profile (B-B') was modeled taking a simplified initial model (Fig.14). This preliminary model was carried out using the least number of layers from the resistivity-depth transformation of the observed data. Therefore, it portrays three dominant geoelectric layers where the resistive layer of gravel is underlain by two geoelectric layers corresponding mainly to sandy clay and clay. This indicates that TEM data could produce the gross boundaries if it is not constrained by a priori information. The top resistive layer of gravel is also well differentiated from the underlain conductive zones though a simplified initial model.

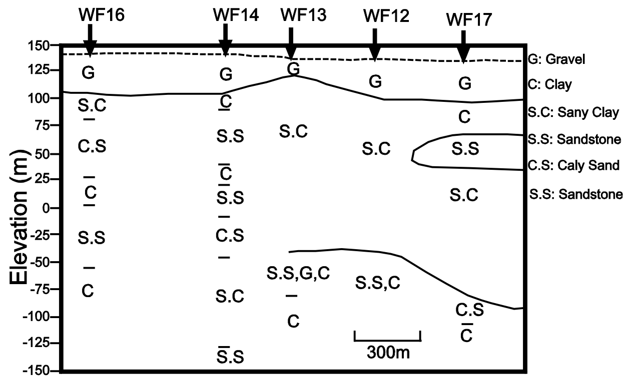


Fig.13: Litho-stratigraphic succession at the borehole sites passing through profile A-A-

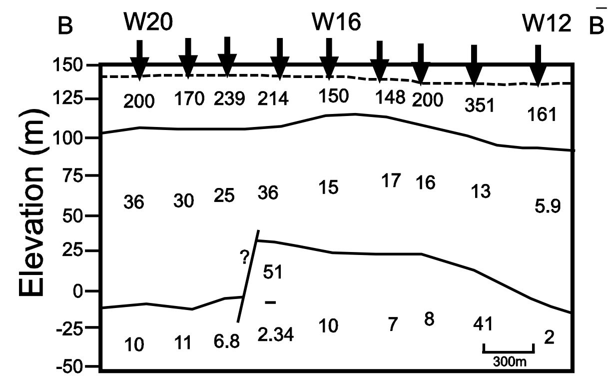


Fig.14: 2-D geoelectric section along profile B-B- using 1-D inversion results

Comparative study between Well log analysis and TEM data

As shown earlier, TEM in most of the data sets is very sensitive to conductive zones. Since we have well log records representing porosity logs (density, neutron, and sonic), shallow and deep resistivity logs, gamma ray, self potential and caliper logs in most wells, these data were first corrected for environmental effects and then analyzed to obtain the most important parameters which might control TEM resistivity values. These are total porosity, volume of shale (clay) and matrix. The output results were presented vertically and compared with TEM resistivity data. A selective example is portrayed in figure (15). As shown, the resistivity values are generally affected by the above mentioned hydrogeophysical parameters, particularly the volume of clay, which plays an important role in the variation of TEM resistivity values.

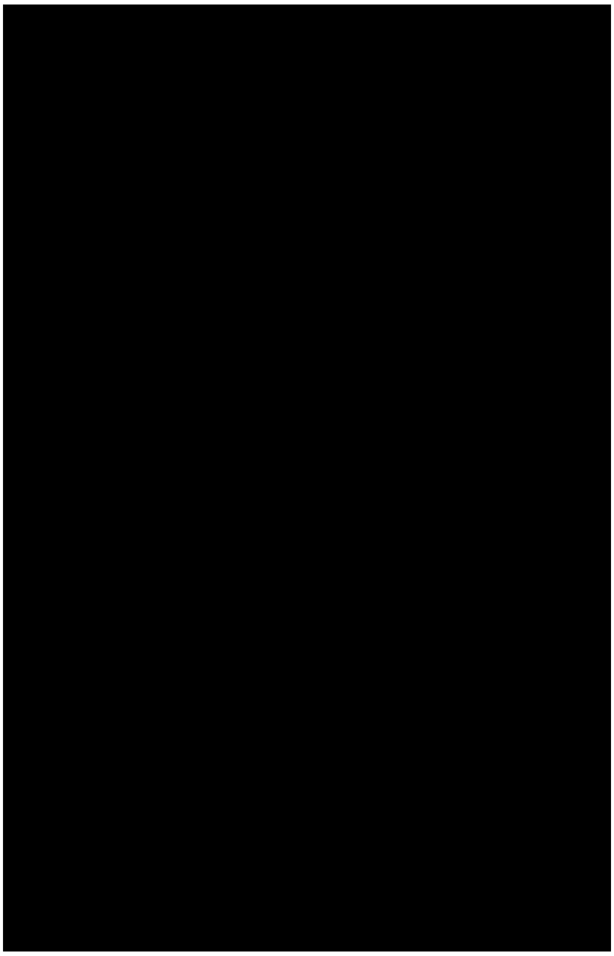


Fig.15: A comparative study between well log analyses and TEM apparent resistivity values at wf 13.

Conclusions and recommendation

The following conclusions may be drawn for this work

1) The method enables a good assessment of the resistivity characteristics of the unconsolidated sediments of sandstone and clay that underlie assemblage boulders of gravel with an average thickness of about 35m.
2) The transient electromagnetic method was able, in most cases, to recognize systematic changes in resistivities of the heterogeneous alluvium deposits, related mainly to variation of lithology. The clay minerals in particular have shown its effectiveness in controlling the TEM voltages.
3) Applications of apparent resistivity-depth transformation to TEM field data for such geological environments show its help for obtaining a simplified initial model even if there is no a previous information.
4) TEM method is well recommended for easy identification of electrical static shift in direct current (DC) sounding curves in such environment.
5) The clay layers have been differentiated from the water bearing formation in most TEM soundings.

Although the 1-D interpretation has proved feasible and reliable in many practical cases, significant inaccuracies may occur when true geoelectrical structure is essentially multidimensional. In this case, multidimensional inversion scheme would be more useful. We hope future work will enable us to collect data set (3-D survey) for 3-D modeling scheme.

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